The electricâ€‘vehicle transition shifts the geography of carbon emissions along global supply chains

Topic: Structural Change and Economic Dynamics
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Although electric vehicles (EVs) are widely promoted as a cornerstone of transport decarbonization, their climate benefit depends on carbon intensive and geographically concentrated upstream supply chainsâ€”especially batteries, basic metals and the electricity used to produce them. Yet the magnitude and cross border distribution of production related (â€œembodiedâ€•) emissions along global EV supply chains, and the resulting implications for carbon accounting and EV incentives, remain poorly quantified in a trade consistent framework. Here we develop an EV extended inter country inputâ€“output (EV ICIO) supply chain accounting framework that disaggregates the automotive sector in the OECD ICIO tables into EVs, internal combustion engine vehicles (ICEVs) and shared components. By integrating firm level bill of materials information from EV manufacturers with bilateral trade statistics, we reconstruct EV specific intermediate input structures and trace value creation and COâ‚‚ emissions across countries and sectors for 2023. We further combine these production footprints with country specific use phase intensities to estimate life cycle emissions and the time required for EVs to reach carbon parity with comparable ICEVs, and we simulate parity dynamics to 2035 under six pathways combining power sector decarbonization and electric drivetrain efficiency gains.

We find that EV supply chains are more centralized than those for conventional vehicles, amplifying the importance of a small set of upstream hubs. At the assembly level, China and Germany together account for 49% of global EV export value in 2023. Upstream stages are even more concentrated: China absorbs 63.1% of global cobalt imports and 64.5% of lithium carbonate imports, and supplies 53.8% of global battery system exports. This topology is mirrored in the geography of embodied emissions. For EVs assembled in China, 80.2% of production related emissions embodied in vehicles arise within China, consistent with co location of energy and materials intensive upstream stages. By contrast, 69.1% and 73.6% of upstream emissions embodied in EVs assembled in the United States and Germany, respectively, occur outside domestic territory, concentrated in electricity generation, basic metals and battery related supply chains. Sectoral decomposition shows that EV production concentrates emissions in fewer upstream sectors than ICEV production: in developed economies and Mexico, electricity generation and basic metals account for 41â€“54% of embodied EV production emissions (electricity alone contributes 25â€“34%). Battery related processes account for around 60% of total EV production emissions, making the carbon intensity of upstream electricity and industrial systems a dominant determinant of EV footprints worldwide.

Life cycle accounting indicates that EVs ultimately deliver lower emissions than ICEVs, but the payback period for the initial â€œcarbon debtâ€• varies sharply with grid carbon intensity and driving activity. In 2023, EVs reach carbon parity after 1.7 (Â±0.2) years in the United States but up to 7.6 (Â±0.8) years in Japan, with intermediate parity times in Germany (3.8), South Korea and Mexico (3.7) and China (6.0). Under business as usual decarbonization, parity times decline by 32â€“60% by 2035; combining accelerated clean power transitions with drivetrain efficiency gains reduces payback times by a further 22â€“25% relative to business as usual (about 23.5% on average). Together, these results show that the EV transition changes not only how much but whereâ€”and in which sectorsâ€”mitigation must occur, implying that territorial, use phase metrics alone may misalign electrification incentives with upstream decarbonization priorities in batteries, metals and electricity.